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December 1992
Roofing Materials Degradation Processes

Three-Year Field Test Summary for Experimental Modified Bitumen Roofing at Fort Polk, LA

by
David M. Bailey
Walter J. Rossiter
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This report presents results of the first 3 years of a 10-year field evaluation on three modified bitumen roofing systems at Fort Polk, LA. This work is part of a research effort being conducted by the U.S. Army Construction Engineering Research Laboratories (USACERL) to attempt to identify alternative, easy-to-install roofing systems that can improve the performance of Army roofing while reducing life-cycle costs.

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13. ABSTRACT (Maximum 200 words)

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FOREWORD

This research is being conducted for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Project 4A162784AT41, "Military Facilities Engineering Technology"; Work Unit MA-CV2, "Roofing Materials Degradation Processes." The technical monitor is Rodger Seeman CEMP-ES.

The work is being performed by the Engineering and Materials Division (FM), of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). David M. Bailey is the principal investigator. Dr. Walter J. Rossiter, Jr., is a research chemist and James F. Seiler, Jr., is a senior research technician at the National Institute of Standards and Technology (NIST). Dr. Paul Howdyshell is Chief, CECERL-FM, and Dr. Michael J. O'Connor is Chief, CECER-FL. The technical editor was Gloria J. Wienke, Information Management Office.

Appreciation is expressed to Fort Polk, LA for providing the building and construction funds for the program and for allowing the removal of samples from the roofs, and to James F. Seiler, Jr., NIST, for performing mechanical and physical tests on the material samples.

COL Daniel Waldo, Jr., is Commander and Director of USACERL and Dr. L.R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

Army installations have traditionally used built-up roofing (BUR) for low-slope roofs, in both new construction and reroofing. Because of several variables such as building design, local labor force, environmental conditions, local construction inspection and quality control practices, and level of maintenance, some of these built-up roofs have failed prematurely, resulting in high life-cycle costs that are difficult for overburdened Army Operation and Maintenance (O&M) budgets to absorb. Therefore, Headquarters, U.S. Army Corps of Engineers (HQUSACE) asked the U.S. Army Construction Engineering Research Laboratories (USACERL) to investigate low-slope roofing systems that can provide alternatives to BUR systems and improve the performance of Army roofing while reducing life-cycle costs. This investigation includes (1) evaluating innovative roofing systems and materials as alternatives to BUR, (2) providing a way to improve Army roof performance and reduce life-cycle costs, (3) improving contractor quality control (CQC) of roofing construction, and (4) developing guide specifications for selected alternative systems.

Roofing research previously published by USACERL has included an overview of alternative reroofing systems (Marvin et al. 1979), investigations of polyvinyl chloride (PVC) single ply systems (Rosenfield March 1981), sprayed polyurethane foam roofing with protective coatings (Rosenfield November 1981), uncured elastomeric systems (Rosenfield February 1986), and standing seam metal roofing systems (Rosenfield, Rose, and Dillner 1986). As a result of an investigation of modified bitumen roofing systems for use in military construction (Rosenfield et al. 1986), three modified bitumen roofing systems were constructed for field evaluation on Building 920 at Fort Polk, LA (Bailey 1991).

Objective

The objective of this interim report is to document the results after 3 years of the 10-year field test of modified bitumen roofing at Fort Polk.

Approach

Field testing of the modified bitumen roofing involved the following procedures:

1. Select three different modified bitumen roofing systems based on findings in earlier USACERL studies (as cited above),

2. Develop a test plan using American Society for Testing and Materials (ASTM) test methods,

3. Develop test guide specifications,

4. Monitor construction of the test roofing systems,

5. Collect test data for 3 years after completion of construction, and

6. Visually inspect each roof once a year.

Mode of Technology Transfer

It is recommended that the results of this study be used to revise Technical Manuals and Corps of Engineers Guide Specifications for modified bitumen membrane roofing. It is also recommended that this information be used in developing and revising ASTM standard procedures as applicable.

2 DESCRIPTION OF TEST PROGRAM

Construction of Test Roofs

Researchers selected Building 920, the Non-Commissioned Officers' (NCO) Club at Fort Polk, LA, for application of three types of modified bitumen roofing systems. The building is used for a club, dining facility, and small retail operations. To separate the different roofing systems, the existing roof was divided into three major areas. Area A is separated from the other areas by an area divider running north and south across the building. An area divider running east and west separates areas B and C. Area B includes a small entryway roof on the north side of the building. The major roof areas are structurally sloped, to drains on the north and south edges, at the rate of 1/2-in./ft.* Figure 1** shows the three different roof areas.

The three membranes selected for the Fort Polk project were specified as follows:

Membrane A—a torch-applied APP (atactic polypropylene) modified bitumen with polyester reinforcement and factory-applied granule surfacing (area A),

Membrane B—a hot-mopped SBS (styrene butadiene styrene) modified bitumen with polyester reinforcement and factory-applied granule surfacing (area B), and

Membrane C—a self-adhering modified bitumen membrane with a polyester film carrier sheet and a vinyl acrylic coating applied in the field (area C).

The contract for reroofing Building 920 specified complete removal of the existing built-up roof system down to the ribbed metal roof deck. After removing the existing roof, workers used steel self-tapping screws and plates to mechanically fasten a layer of perlite insulation board to the deck. They installed a two-ply asphalt and felt vapor retarder over the perlite. Two layers of polyisocyanurate board, complying with Federal Specifications HH-I-1972/GEN and HH-I-1972/2 Class I, then were placed in solid moppings of asphalt over the vapor retarder. The boards are faced with asphalt/glass fiber felt. The insulation thicknesses for the field of the roof was calculated to provide a minimum 0.063 U-value for all roof areas. Figure 2 is a schematic of the roofing materials.

The specifications for application of the three membrane systems reflected the differences between the membrane materials. On area A, a nonperforated base sheet was installed over the top layer of insulation in spot moppings of hot asphalt. The membrane A material was torch-applied over the base sheet. For area B, the base sheet was solid-mopped rather than spot-mopped. The membrane B material was fully mopped to the base sheet with Type IV asphalt. For area C, the membrane C material was directly adhered to the top layer of polyisocyanurate insulation.

Test Program

The test program was designed to determine changes in the mechanical and physical characteristics of the different membrane materials as they weathered in service. Properties selected for study were those deemed important to successful performance of the materials in a roof assembly and have been used to characterize modified bitumens. Five specimens were tested for each property.

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*A metric conversion table is on page 28.
**Tables and figures are at the end of each chapter.

Researchers conducted an initial set of laboratory tests to establish the characteristics of the materials at the time of application. Subsequent tests are scheduled at 1-year intervals for 10 years. These tests will provide data on changes in the physical and mechanical properties as the membranes age in service and will allow comparisons between the magnitude of any changes in properties and the observed performance of the roofing systems. In addition to the laboratory tests, the roofs will be inspected visually each year to check for changes in appearance, loss of adhesion of the membrane sheets to their substrate, cracking, blistering, and evidence of mechanical damage from rooftop traffic, unauthorized attachments, or penetrations.

Table 1 lists the properties being tested and the basis of the test procedures used. Most of the tests were selected from ASTM D 5147-91 "Standard Test Methods for Sampling and Testing Modified Bituminous Sheet Material" (ASTM 1991; the Draft Standard was used for this research). The static and dynamic puncture tests were selected from the recommendations of the CIB/RILEM (International Council for Building Research, Studies, and Documentation/ International Union of Testing and Research Laboratories for Materials and Structures) Committee on Elastomeric, Thermoplastic, and Modified Bituminous Roofing (National Institute of Standards and Technology 1988). This committee considered puncture resistance one of the important engineering properties of membrane materials that should be considered in assessing membrane performance.

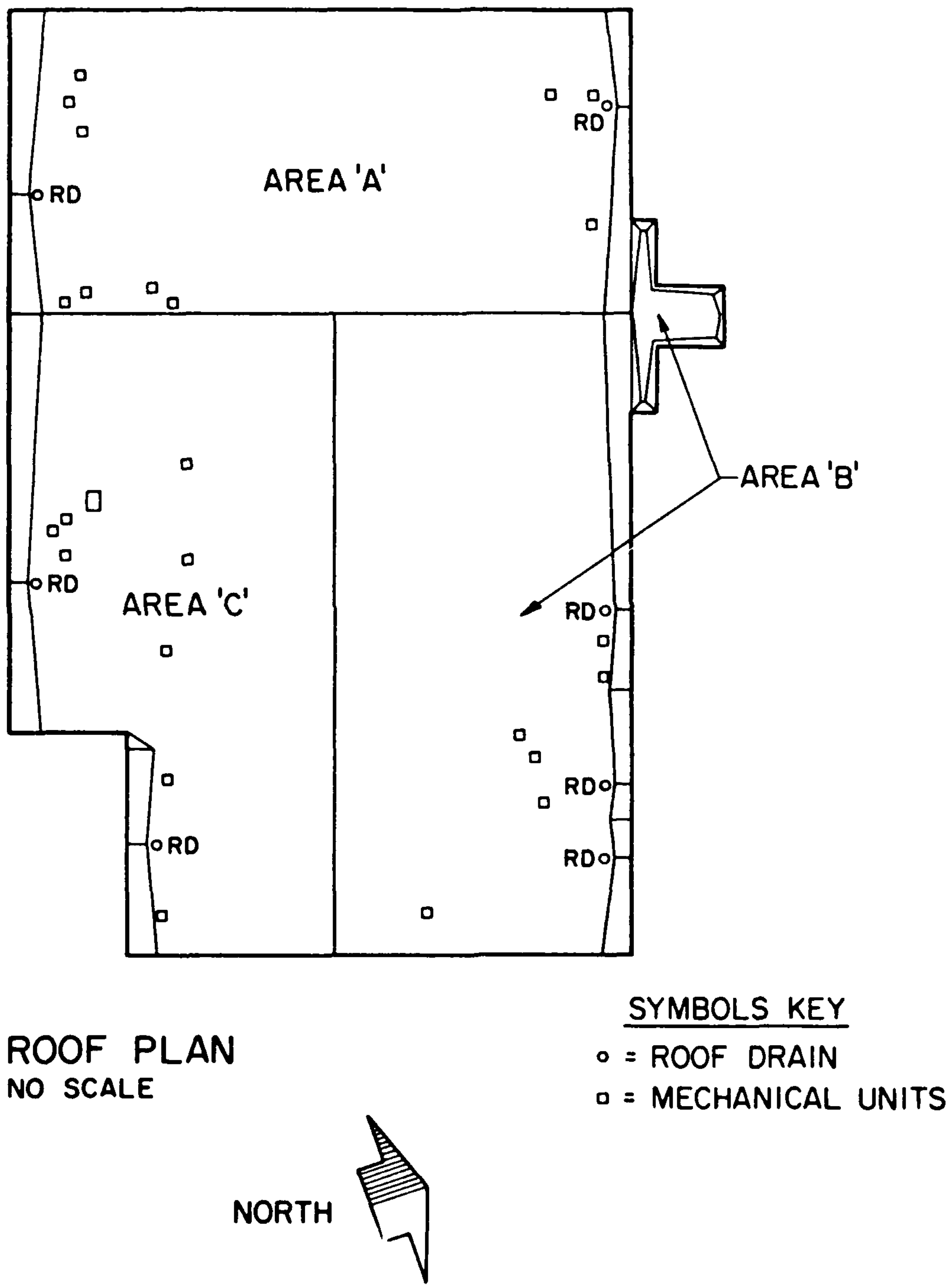

Figure 1. Roof Plan for Building 920 at Fort Polk.

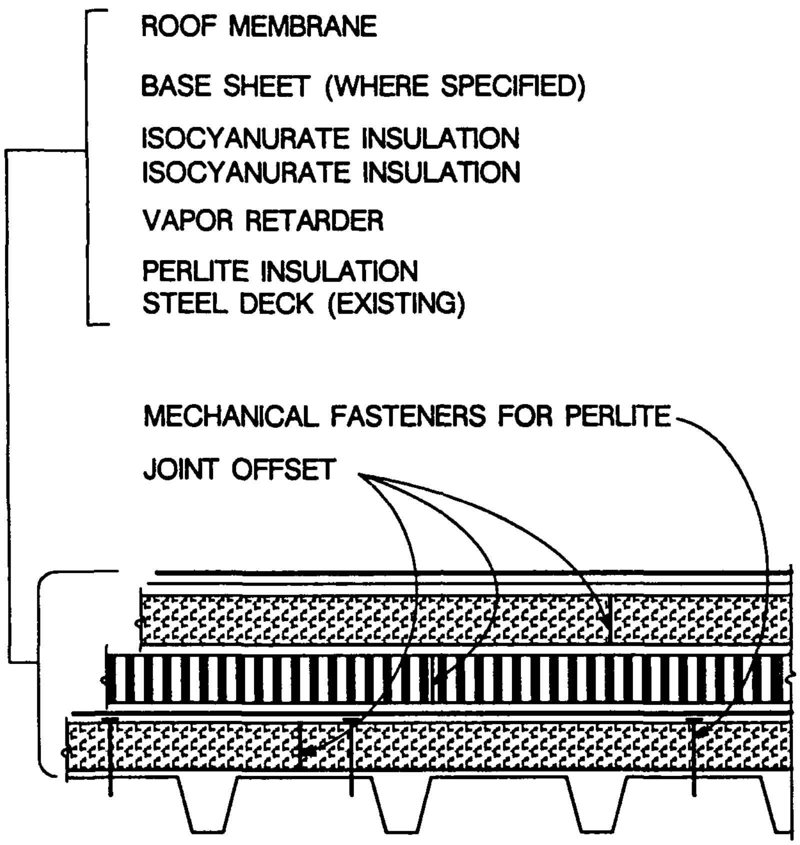

Figure 2. Schematic of Roofing Materials.

Table 1

Properties Determined for the Modified Bitumen Membrane Materials

Property	Test Procedure
Thickness	ASTM D 5147, section 5[a]
Tensile Strength at O °F (-18 °C)	ASTM D 5147, section 6
Elongation at O °F (-18 °C)	ASTM D 5147, section 6
Strain Energy at O °F (-18 °C)	ASTM D 5147, section 6
Tear Resistance	ASTM D 5147, section 7
Moisture Content	ASTM D 5147, section 8
Low-Temperature Flexibility	ASTM D 5147, section 11
Static Puncture	UEAtc MOAT No. 27, section 5.4.1[b]
Dynamic Puncture	NF P 84-353[b]

[a]The ASTM procedures are given in "Standard Test Methods for Sampling and Testing Modified Bituminous Sheet Material."
[b]This test procedure is given in the 1988 report of the CIB/RILEM Committee on Elastomeric, Thermoplastic, and Modified Bituminous Roofing. The report is titled "Performance Testing of Roofing Membrane Materials."

3 PHYSICAL AND MECHANICAL PROPERTY CHANGES

Initial Properties

The initial properties of the three membrane materials, as determined from samples prepared by the contractor during installation of the roofs, are listed in Table 2. The membrane A specimen was tested as a composite of the modified bitumen sheet with the glass fiber base sheet. The torch application of the modified bitumen resulted in a two-ply composite that could not be readily delaminated without damaging the modified sheet. The membrane B specimen was tested as a single sheet since the modified bitumen ply was readily delaminated from the base ply by cooling the composite specimen. The membrane C specimen was tested with the white vinyl acrylic coating in place.

Suggested National Institute of Standards and Technology (NIST) criteria have been recommended for only three of the tests being performed: strain energy, minimum 0.5 kN • m/m^2; low temperature flexibility, maximum 0 °C; and moisture content, maximum 0.5 percent (Rossiter and Seiler 1989). All three membranes met the low temperature flexibility and moisture content requirements. However, membrane A did not meet the minimum strain energy criteria with reported values of 0.40 and 0.33 kN • m/m^2 in the longitudinal and transverse directions, respectively. For these test roofs located in Louisiana, where extremely harsh cold temperatures may not occur, the membrane should not be subjected to temperature-induced stresses as great as if it were located in colder regions of the country. The result is that the risk of membrane splitting may be reduced. It will be of particular interest in the study to follow the long-term performance of a membrane whose initial properties do not meet the strain energy criteria suggested by NIST.

The data in Table 2 also show that the longitudinal tensile strength and elongation of membrane A were about 36 kN/m and 1.5 percent, respectively. These properties were characteristic of a modified bitumen sheet having glass reinforcement and not polyester, which was specified for this product. Reasons for this discrepancy were not known. A possibility is that the tensile strength and elongation properties were influenced by the presence of the glass fiber base sheet in the composite membrane tested.

Property Changes

The measured property values for each membrane are included in Tables 3, 4, and 5. The changes in properties were analyzed using a software program called "Dataplot" (Filliben 1981). For the preliminary analysis, a linear model relating the value of the measured property to the sample age was used. If a relationship existed, the slope of the line statistically different from zero (0.05 significance level or less) was used as the criterion for determining whether a change in property value occurred. Mechanical properties were measured in both the longitudinal and transverse direction of the membrane material.

Membranes A, B, and C are designated as samples 1, 2, and 3 respectively, in the plots and discussion of the data. No data are given for sample 1 at year 2 because the piece of membrane A material taken at that time contained only the membrane ply; the samples of the same material taken at other times contained both the membrane and base plies adhered together.

Thickness

For clarity in presenting the data, the individual measurements for each year are slightly spread apart in the plot shown in Figure 3. Samples 1 and 2 show variation in thickness for the specimens tested at different times. No relationship between the two measurements was found. The variations in thickness were not unexpected as samples 1 and 2 were obtained from roofs in service and the installation of the membrane materials undoubtedly affected the thickness. In the case of sample 1, the material was "torch applied," which causes the asphalt on the sheet to soften and flow. Nonuniform flow will result in sections of the installed sheet being relatively thin or thick. In the case of sample 2, the material was applied in a layer of hot asphalt, which would also have variations in thickness.

Sample 3 displays a relatively constant thickness over the range of measurements. This sample, which had a self-adhering bottom layer, was applied without heating or hot asphalt. Thus, its thickness might not be expected to vary. On the other hand, the sample contained a spray-applied coating which was present on the specimens on which the thickness measurements were made. Nonuniform application of the coating would have resulted in variations of the thickness measurements.

Tensile Strength

Figure 4 presents the tensile strength data. For samples 1 and 3 in the longitudinal direction, and sample 3 in the transverse direction, the observed decreases in tensile strength with time were statistically significant. The greatest change in strength was a 21 percent* decrease exhibited by sample 3 in the longitudinal direction. Sample 1 in the transverse direction displayed a 13 percent decrease in strength, but it was not statistically significant. Sample 2 showed no statistically significant change in strength in either direction.

Elongation

Figure 5 presents elongation data. Sample 1 showed an elongation of 1 to 3 percent, depending on its age. The modified membrane material in the sample contained a polyester reinforcement that would be expected to provide elongations greater than 3 percent. However, the sample tested in tension was the 2-ply modified bitumen/glass felt composite. The presence of the glass felts, which may rupture in tension at about 3 percent, apparently influenced failure of the composite and limited the elongation.

Sample 1 showed statistically significant increases in elongation in both directions over time. The increases were about 100 percent, which was the greatest percent change observed for any of the samples. Sample 2 in the longitudinal direction showed a statistically significant decrease with time; whereas in the transverse direction it showed no statistically significant change. Sample 3 also showed statistically significant decreases in elongation in both directions.

Strain Energy

Figure 6 presents strain energy data. Sample 1 in both directions and sample 2 in the transverse direction showed no statistically significant changes in strain energy. Sample 3 in both directions and sample 2 in the longitudinal direction showed statistically significant decreases. The greatest percent decrease was about 50 percent for sample 3 in both directions; sample 2 in the longitudinal direction showed a 15 percent decrease. The values for sample 1 in both directions were less than the NIST recommended minimum of 0.5 $kN \cdot m/m^2$.

* The percentages are derived from averages of the numbers in Tables 3, 4, and 5. Figures 4 through 7 graphically represent the overall trends in property changes.

Tear Resistance

Figure 7 presents strain energy data. Only for sample 1 was a statistically significant decrease in tear resistance in both directions observed over time. The amount of change after 3 years of exposure was 28 percent in the longitudinal direction and 21 percent in the transverse directions. Samples 2 and 3 showed no statistically significant changes in either direction.

Moisture Content

No significant changes in moisture content were observed (Figure 8). With the exception of one measurement (sample 3 at 2 years), none of the values of moisture content exceeded the NIST recommended maximum value of 0.5 percent by mass.

Low Temperature Flexibility

Sample 1 showed an increase in low temperature flexibility (LTF) of about 40 °C after 3 years (Figure 9). Its initial LTF value point was -18 °C, which is typical of many modified bitumen membrane materials. The sample tested after 3 years showed cracking or crazing on bending at room temperature (about 22 °C). Reasons for this observed behavior are not proposed at this time since the data are limited. Moreover, because the data are limited (only 2 points in time), it could not be ascertained whether the observed change had a statistical significance.

Samples 2 and 3 showed statistically significant increase in LTF with time, resulting in LTF values of -10 °C and -15 °C, respectively. In both cases, the extent of the changes was 21 °C after 3 years.

Static Puncture

The test procedure to evaluate static puncture resistance subjects the membrane material to a maximum load of 245 Newtons (Figure 10). None of the samples at any age failed at the maximum static puncture load.

Dynamic Puncture

Samples 1 and 3 showed no statistically significant changes in dynamic puncture resistance with time (Figure 11). Sample 2 showed a 28 percent decrease, which was statistically significant.

Table 2

Initial Properties of the Three Test Membranes

Property	**Membrane**	**Membrane**	**Membrane**
	A	**B**	**C**
Thickness (mm)	7.9	6.4	2.8
Tensile Strength (kN/m)			
Longitudinal	36	26	24
Transverse	30	19	23
Elongation (%)			
Longitudinal	1.5	21	24
Transverse	1.6	25	27
Strain Energy (kN • m/m^2)			
Longitudinal	0.40	4.0	4.0
Transverse	0.33	3.5	4.6
Tear Resistance (N)			
Longitudinal	1030	658	543
Transverse	778	547	605
Moisture Content (mass %)	< 0.2	< 0.2	< 0.2
Low-Temperature Flexibility (°C)	-18	-31	-36
Static Puncture (lb)	245+	245+	245+
Dynamic Puncture (Joules)	20	18	7.5

Table 3

Initial and Aged Properties of Membrane A (Sample 1)

Property		Initial	Year 1	Year 2	Year 3
Thickness (mm)					
Avg		7.9	9.1	--	6.4
Range		6.9 - 9.7	8.6 - 10.0		5.6 - 6.4
Tensile Strength (kN/m)					
Longitudinal	Avg	36	33	--	25
	Range	33 - 38	32 - 34		24 - 28
Transverse	Avg	30	21	--	26
	Range	25 - 34	20 - 22		22 - 32
Elongation (%)					
Longitudinal	Avg	1.5	2.2	--	3.0
	Range	1.3 - 1.9	2.0 - 2.3		2.9 - 3.2
Transverse	Avg	1.6	2.6	--	3.0
	Range	1.3 - 1.9	2.5 - 2.8		2.8 - 3.3
Strain Energy ($kN \cdot m/m^2$)					
Longitudinal	Avg	0.40	0.35	--	0.32
	Range	0.35 - 0.44	0.30 - 0.39		0.30 - 0.36
Transverse	Avg	0.33	0.32	--	0.34
	Range	0.25 - 0.42	0.28 - 0.35		0.29 - 0.46
Tear Resistance (N)					
Longitudinal	Avg	1030	1160	--	740
	Range	903 - 1280	1040 - 1230		663 - 771
Transverse	Avg	778	850	--	614
	Range	747 - 810	712 - 947		587 - 645
Moisture Content (mass %)		< 0.2	< 0.2	--	0.5
Low-Temperature Flexibility (°C)		-18	--		22
Static Puncture (lb)		245+	245+	--	245+
Dynamic Puncture (Joules)		20	22	--	22

Table 4

Initial and Aged Properties of Membrane B (Sample 2)

Property			Initial	Year 1	Year 2	Year 3
Thickness (mm)						
	Avg		6.4	6.4	5.3	6.1
	Range		4.8 - 8.9	5.8 - 6.6	4.3 - 5.8	5.6 - 6.4
Tensile Strength (kN/m)						
	Longitudinal	Avg	26	26	27	26
		Range	17 - 32	25 - 27	25 - 28	23 - 28
	Transverse	Avg	19	15	16	19
		Range	17 - 27	12 - 18	15 - 16	17 - 22
Elongation (%)						
	Longitudinal	Avg	21	19	18	17
		Range	19 - 29	17 - 21	17 - 20	15 - 18
	Transverse	Avg	25	11	23	21
		Range	18 - 29	7 - 15	21 - 25	18 - 24
Strain Energy (kN · m/m^2)						
	Longitudinal	Avg	4.0	4.0	3.9	3.4
		Range	3.7 - 4.6	3.7 - 4.7	3.5 - 4.2	2.8 - 3.9
	Transverse	Avg	3.5	1.4	2.8	3.2
		Range	3.0 - 3.9	0.9 - 1.9	2.5 - 3.2	2.6 - 4.1
Tear Resistance (N)						
	Longitudinal	Avg	658	--	694	610
		Range	512 - 778		623 - 721	565 - 654
	Transverse	Avg	547		538	507
		Range	471 - 747		507 - 565	480 - 520
Moisture Content (mass %)			< 0.2	< 0.2	0.3	< 0.2
Low-Temperature Flexibility (°C)			-31	--	-12	-10
Static Puncture (lb)			245+	245+	245+	245+
Dynamic Puncture (Joules)			18	--	15	13

Table 5

Initial and Aged Properties of Membrane C (Sample 3)

Property		**Initial**	**Year 1**	**Year 2**	**Year 3**
Thickness (mm)					
Avg		2.8	3.3	2.5	3.0
Range		2.5 - 3.0	2.8 - 4.1	2.5 - 2.8	2.8 - 3.3
Tensile Strength (kN/m)					
Longitudinal	Avg	24	16	17	19
	Range	22 - 26	14 - 17	15 - 18	15 - 22
Transverse	Avg	23	17	16	19
	Range	18 - 27	16 - 18	14 - 18	14 - 22
Elongation (%)					
Longitudinal	Avg	24	25	13	15
	Range	23 - 26	23 - 29	10 - 15	10 - 19
Transverse	Avg	27	24	16	17
	Range	21 - 34	23 - 24	13 - 18	13 - 22
Strain Energy (kN • m/m^2)					
Longitudinal	Avg	4.0	3.5	1.6	2.2
	Range	3.7 - 5.1	3.2 - 4.0	1.5 - 2.1	1.1 - 3.0
Transverse	Avg	4.6	3.2	1.9	2.3
	Range	2.6 - 5.8	2.8 - 3.3	1.4 - 2.3	1.4 - 3.3
Tear Resistance (N)					
Longitudinal	Avg	543	912	525	502
	Range	458 - 641	721 - 1170	445 - 676	448 - 583
Transverse	Avg	605	498	605	551
	Range	463 - 770	458 - 525	467 - 694	457 - 641
Moisture Content (mass %)		< 0.2	0.4	0.9	0.4
Low-Temperature Flexibility (°C)		-36	-24	-26	-15
Static Puncture (lb)		245+	245+	245+	245+
Dynamic Puncture (Joules)		7.5	7.5	7.5	10
	Range				

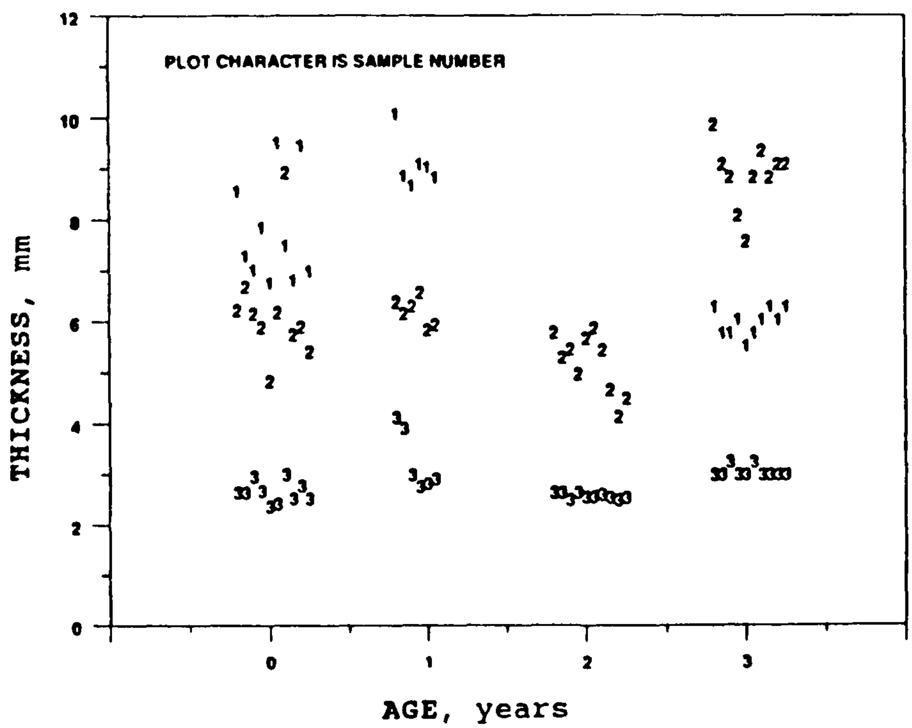

Figure 3. Plot of Membrane Thickness.

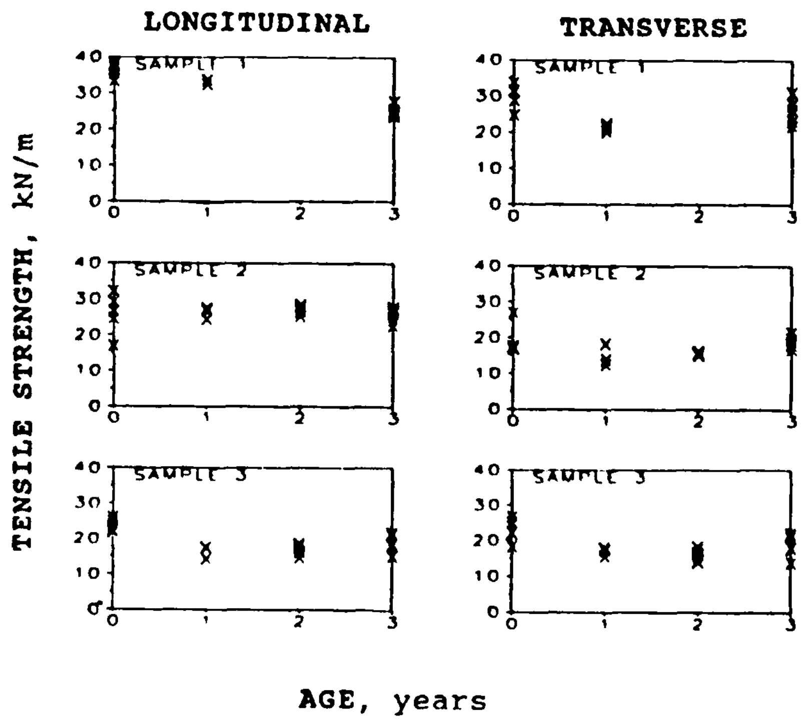

Figure 4. Plot of Membrane Tensile Strength.

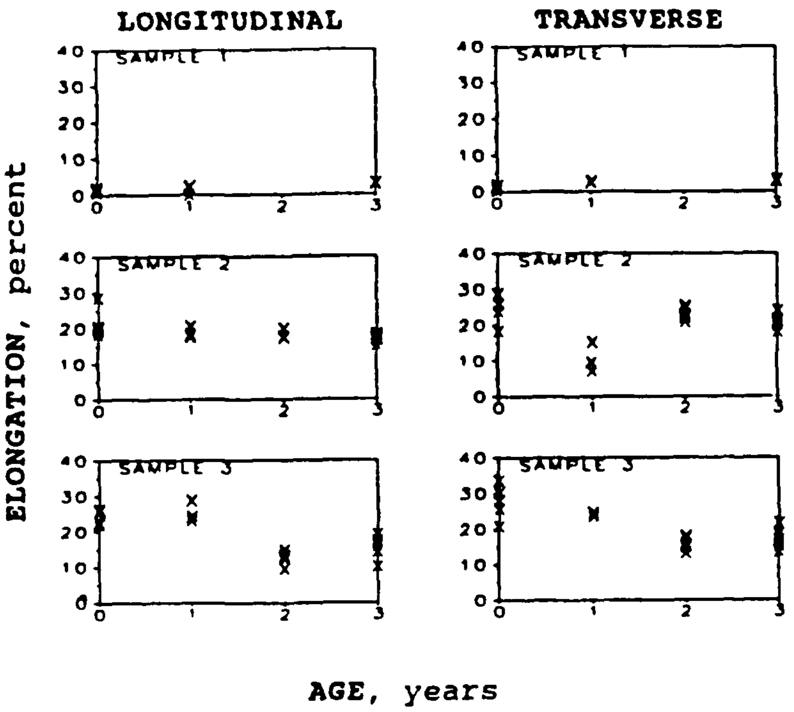

Figure 5. Plot of Membrane Elongation.

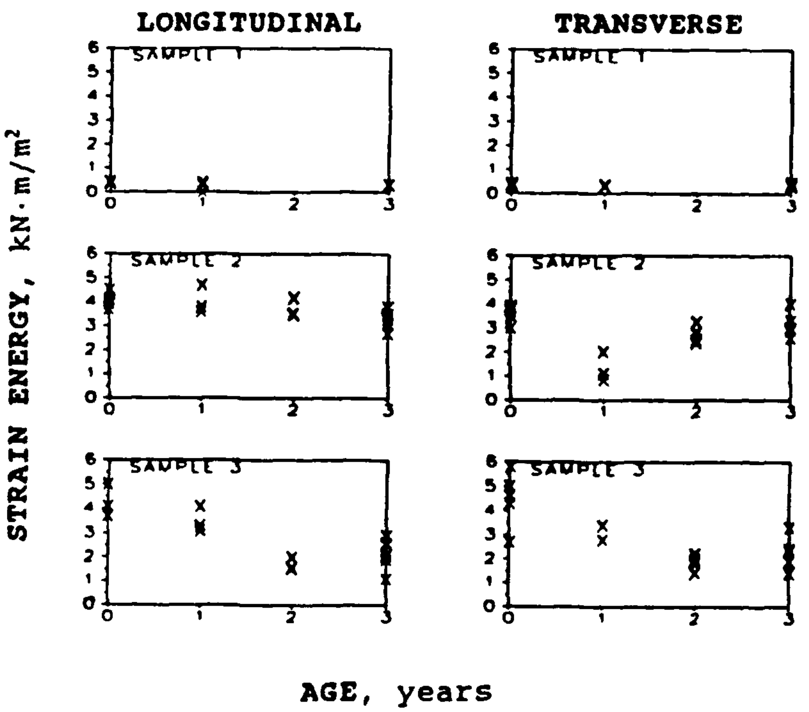

Figure 6. Plot of Membrane Strain Energy.

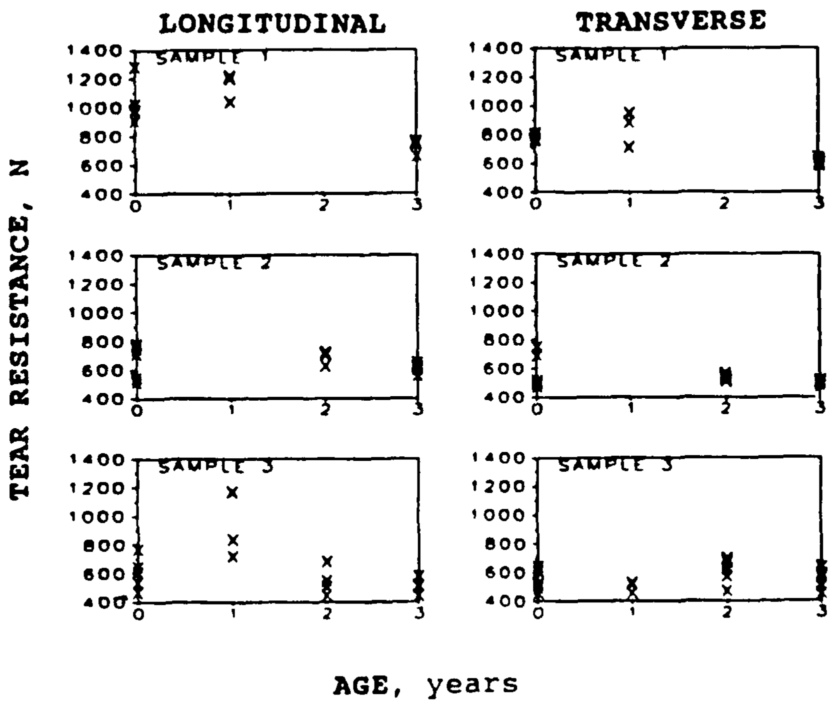

Figure 7. Plot of Membrane Tear Resistance.

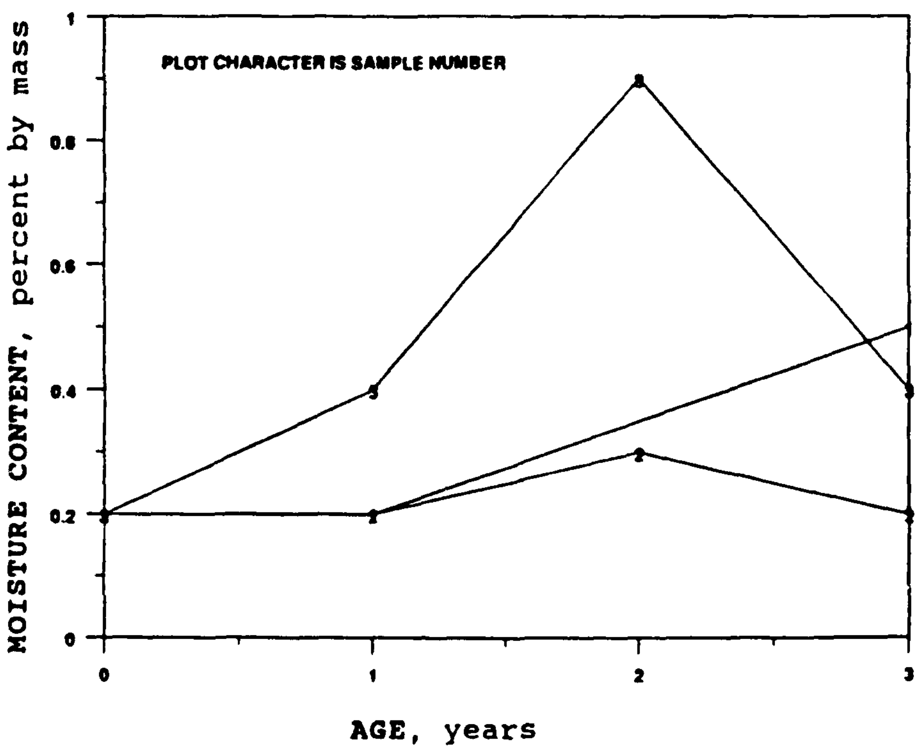

Figure 8. Plot of Membrane Moisture Content.

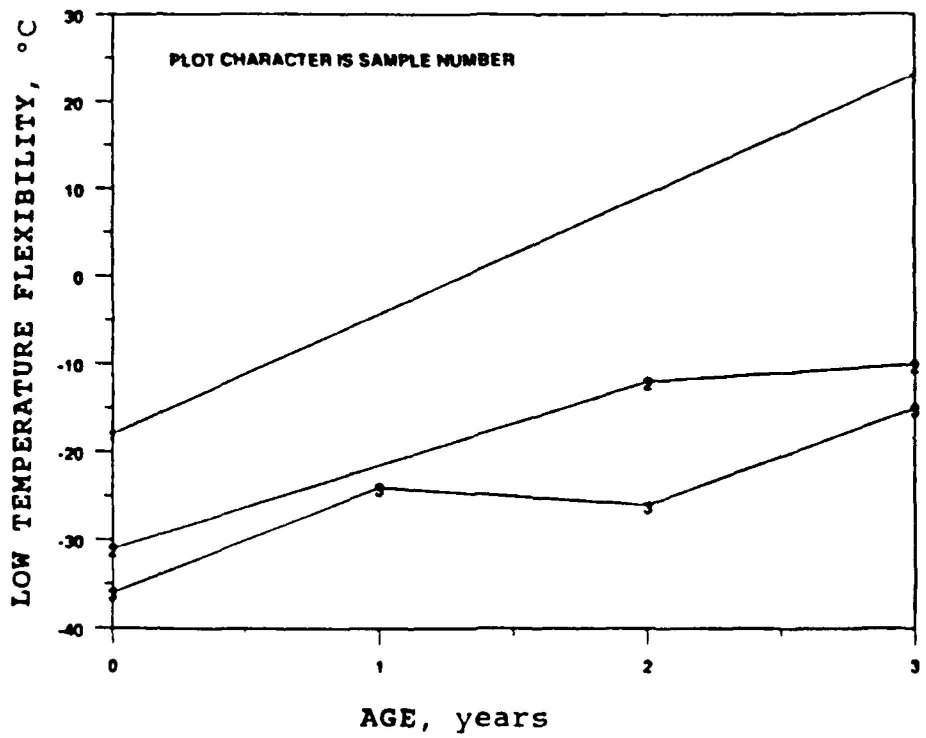

Figure 9. Plot of Membrane Low Temperature Flexibility.

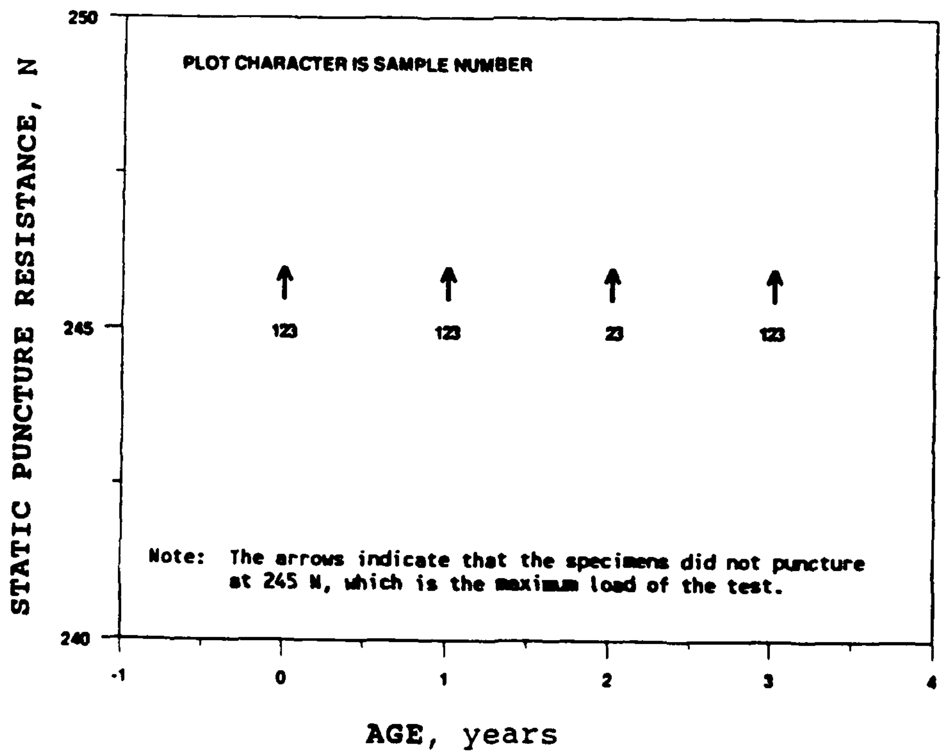

Figure 10. Plot of Membrane Static Puncture.

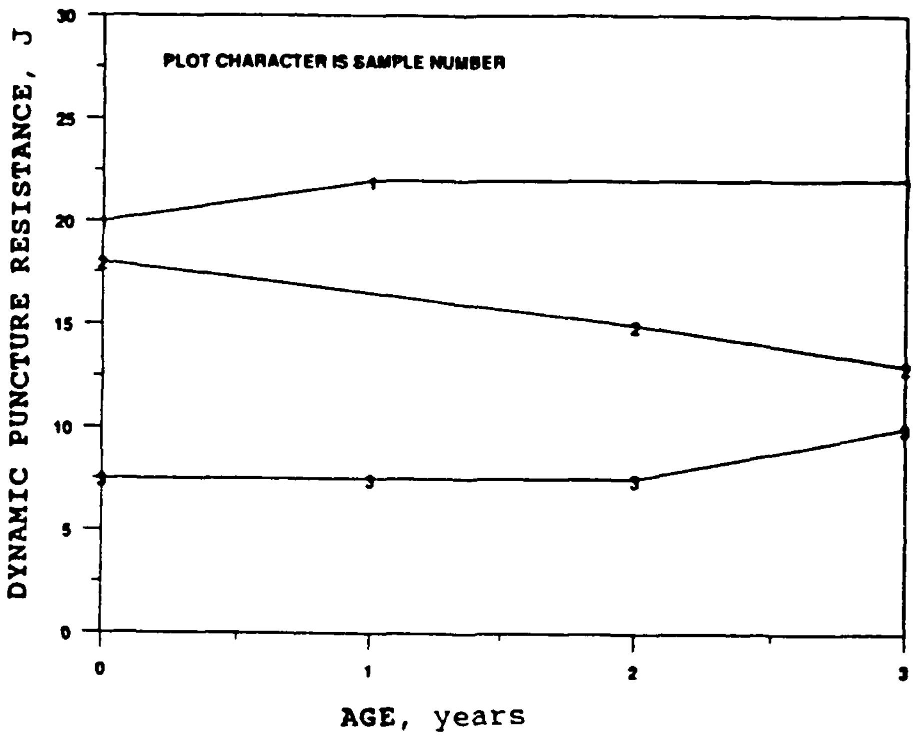

Figure 11. Plot of Membrane Dynamic Puncture.

4 RESULTS OF INSPECTIONS

The test roofs were inspected annually as part of the evaluation process. During each inspection, the roof was carefully checked for visible signs of deterioration, giving special attention to the condition of flashings and patches where test samples had been removed. Areas needing maintenance and repair were also noted. Nondestructive evaluations to characterize the moisture condition of the roofing systems were not conducted as part of this study.

First Annual Inspection

In October of 1988, 1 year after construction was completed, the torch-applied APP modified bitumen (membrane A) and the self-adhering modified bitumen (membrane C) were in excellent condition. No visible changes were noted. However, the hot-mopped SBS modified bitumen (membrane B) had several problems, all of which seemed to be caused by the membrane plys slipping down the roof slope.

Slippage of hot-mopped SBS modified bitumen membrane systems has been noted (Baxter 1987). Baxter indicates that it has been primarily experienced on roofs with significant slopes (1/2 in. per foot or greater) and more often when the membrane plies are installed in shingle fashion (i.e., perpendicular to the slope). These conditions are similar to those existing for membrane B.

The first evidence of slippage was the gap of exposed mopping asphalt running perpendicular to the slope and located at the uppermost part of the roof section (Figure 12). The gap was approximately 4 in. wide and tapered to zero width at the south wall and north area divider. Wrinkles and fishmouths in the membrane lap seams had occurred at locations where the slippage was prevented by roof penetrations (Figure 13).

The existing roof slope is 1/2-in. per ft, which is the industry accepted threshold value for requiring backnailing of the felts to prevent slippage on bituminous built-up roofs. The drawings and specifications had been reviewed by the manufacturer before they were released for contract specification, and were accepted as being in accordance with their requirements.

The researchers decided that anchoring of the membrane would be delayed for part of the following summer to see if the slippage had stopped or was still active.

Second Annual Inspection

The test roofs were reinspected in July of 1989. Membranes A and C remained in excellent condition; no changes in appearance were noticed. No problems were noted with the flashings and only minor wrinkling was apparent in some areas of the membrane. The slippage of membrane B had progressed approximately 1 in. since the previous inspection. Upon taking field measurements, researchers determined the entire membrane was slipping as a unit. At this time, it had become evident that the roof membrane would have to be anchored to prevent any further slippage.

USACERL specified an anchoring procedure that was performed by a roofing contractor. The procedure involved driving screw fasteners through 3-in. diameter metal plates and down through the steel deck. Fasteners were placed every 3 ft along each membrane roll and were staggered on adjacent rolls (Figure 14). The following steps were performed for each fastener:

1. A 9-in. circle was drawn at the fastener location using a template.

2. With the assistance of a heat torch, the mineral granules within the circle were spudded away,

3. A 3-in. diameter metal plate was placed in the center of the circle and a steel screw fastener was driven through the plate and into the metal deck below (Figure 15),

4. The membrane surface within the circle, metal plate, and fastener head were primed and the solvent was allowed to dry before proceeding to the next step,

5. The underside of a 9-in. diameter circular patch of membrane material was heated with a torch, placed over the target area, and adhered, and

6. Using the torch and a trowel, the edges of the patch were sealed with modified bitumen (Figure 16).

To complete the procedure, the wrinkles and fishmouths located around the penetrations were cut and removed, and patched with new membrane material.

Third Annual Inspection

The third annual inspection of the test roofs was conducted in December 1990. Membrane A was in excellent condition with no visible changes. Although no new problems were found on membrane C, the patches over the test cuts had not been recoated with the white vinyl acrylic coating that had been applied to the membrane initially. To ensure that the patches do not deteriorate from exposure to ultraviolet radiation, they were coated.

The anchoring procedure for membrane B was performing well. No further evidence of slippage was noted and the target patches and fishmouth repairs remained watertight.

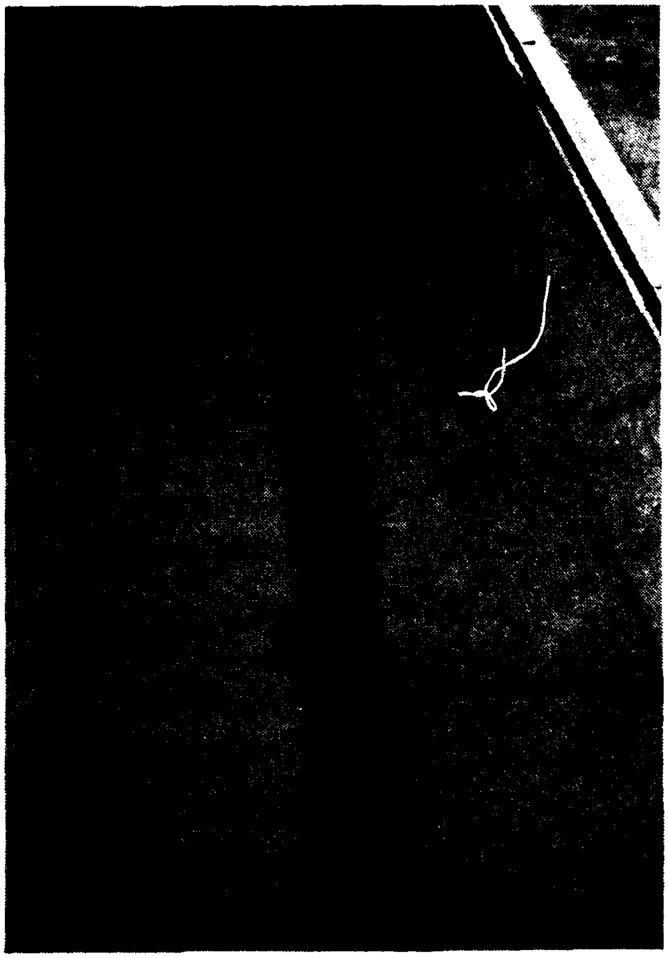

Figure 12. Exposed Asphalt due to Slippage.

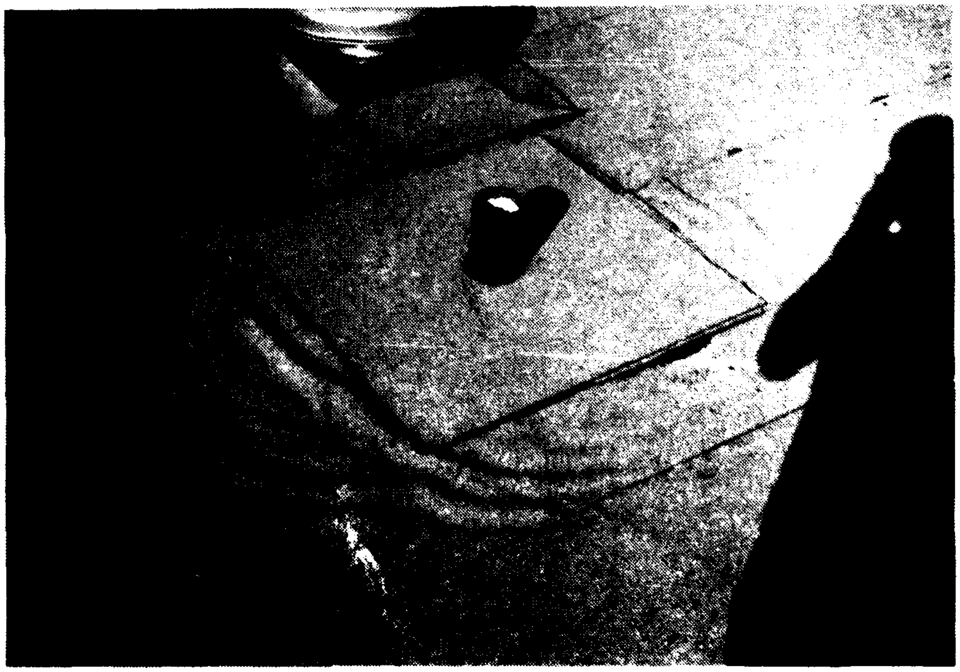

Figure 13. Wrinkles and Dishmouths due to Slippage.

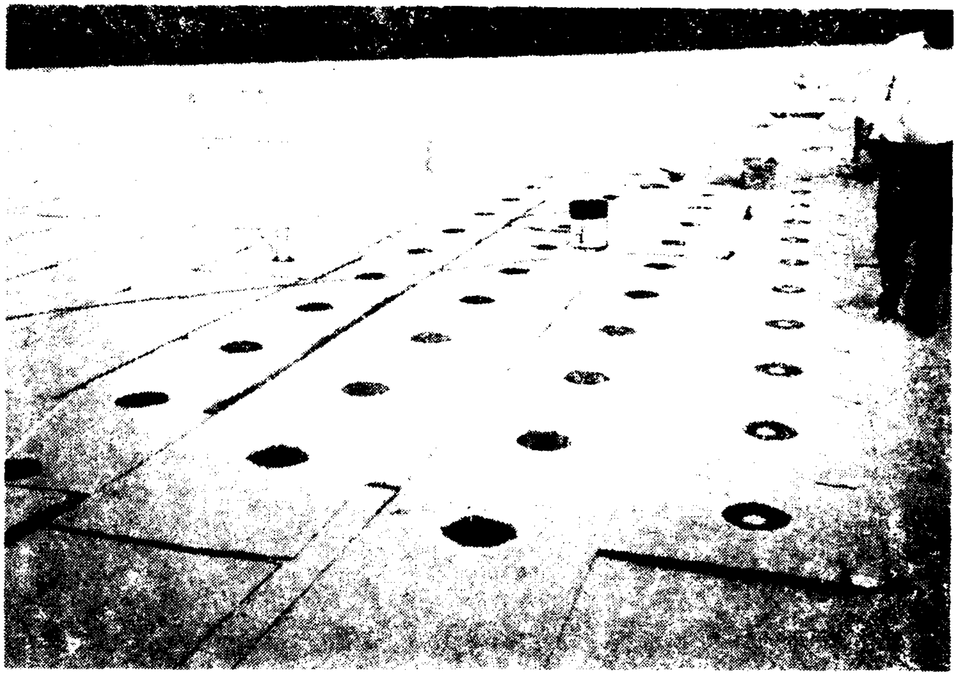

Figure 14. Staggered Anchoring Fasteners on Membrane B.

Figure 15. Placing the Fasteners Through Membrane B.

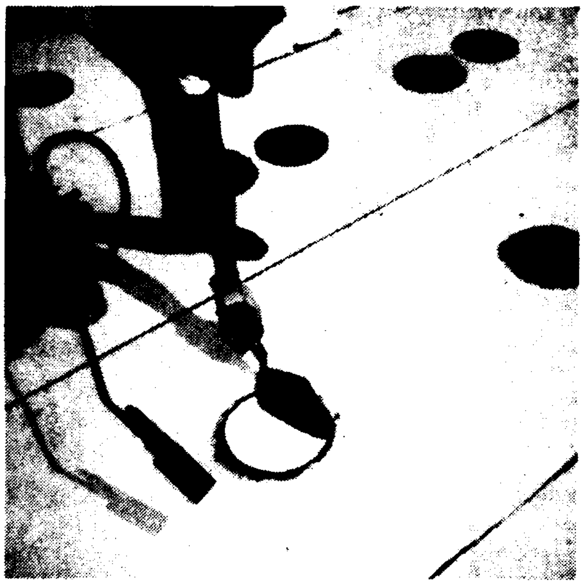

Figure 16. Patching Over the Fasteners on Membrane B.

5 CONCLUSIONS AND RECOMMENDATIONS

Results of the first 3 years of a 10-year field test provide the following information about the three different roofing membrane materials.

- Membrane A exhibited a slight decrease in tensile strength over time. The elongation, which increased with time, and the strain energy were lower than expected; probably due to the sample being tested with the glass fiber base sheet adhered to the membrane. The tear resistance dropped approximately 25 percent while the low temperature flexibility after 3 years was 40 °C higher than the initial value.

- Membrane B experienced no significant changes in tensile strength, elongation, strain energy, and tear resistance. The dynamic puncture resistance decreased slightly and the low temperature flexibility point increased 21 °C over 3 years but both measurements remained below the NIST recommended maximum values.

  The roofing system, which was designed and installed in accordance with the manufacturer's requirements, experienced significant slippage during the first summer. During the second year, a stabilization procedure was implemented; screw fasteners were driven through metal plates and into the steel deck at 3 ft intervals. Slipping of the membrane has since subsided.

- Membrane C exhibited significant decreases in tensile strength, elongation, and strain energy with time. Similar to membrane B, the low temperature flexibility point increased after 3 years but remained below the NIST recommended value.

After 3 years of exposure, the three modified bitumen roofing systems are performing excellently (except for the slippage of membrane B) based on the yearly visual inspections. Continued testing of these roofs will provide a long-term history of the material behavior, allowing a more detailed analysis of changes in membrane properties based on how they weather in service.

This effort should parallel the work being done by ASTM in developing a standard specification for modified bitumen membrane materials. The CEGS should retain current provisions to prevent slippage of modified bitumens particularly on SBS membranes on slopes of 1/2-in. per foot or greater.

METRIC CONVERSION TABLE

1 in.	=	25.4 mm
1 ft	=	0.305 m
1 sq ft	=	0.0929 m
1 kip	=	4448.2 Newton
1 kip	=	1000 lbf
°F	=	(°C+17.78)x1.8

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